150 Years of Menangle Bridge

Bill Phippen

3827 with No. 50 Moss Vale Passenger crosses the Nepean River on 15 May 1965. At this time, Menangle Bridge had already celebrated 100 years of service. NJ Simons collection, ARHSnsw Railway Resource Centre 62650

The first of July 1863 was a notable day in the history of the New South Wales Railways. Ernest Edward Lucy was celebrating his second birthday, and coincidentally he would formally take office as the Chief Mechanical Engineer of the New South Wales Government Railways on that same date — his 50th birthday — in 1911.

Just south of Sydney on that day the Great Southern line was extended across the Nepean River and through to Picton. This extension would be followed by others until the line reached Albury and the colonial border in 1881. With some deviations, that route essentially remains as the link between Sydney and Melbourne.

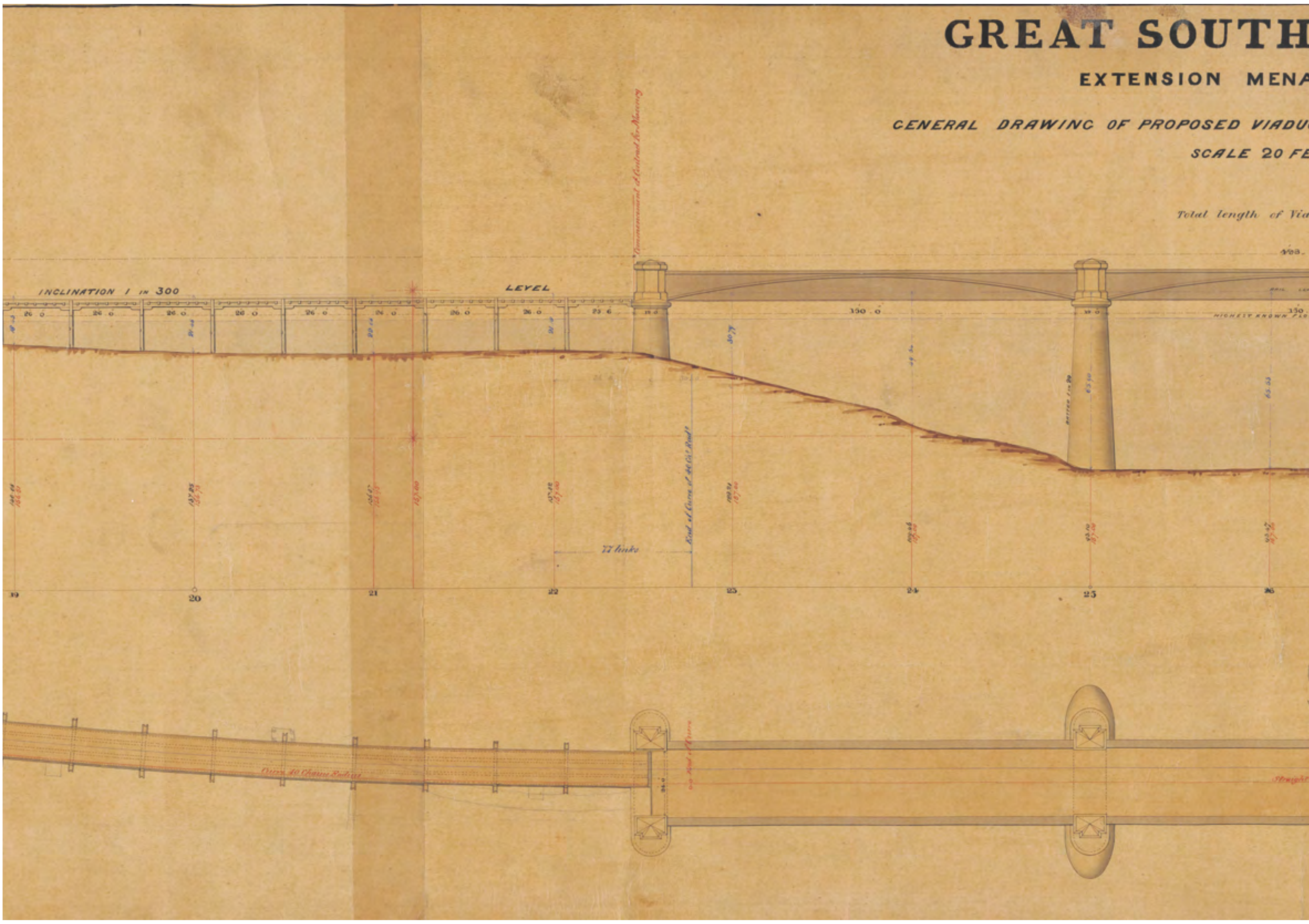
To cross the Nepean River a large and controversial iron bridge was provided, and remarkably that bridge is still in place, still carrying the double tracks which each day bear the weight of express passenger trains, commuter trains, coal trains and interstate freights.

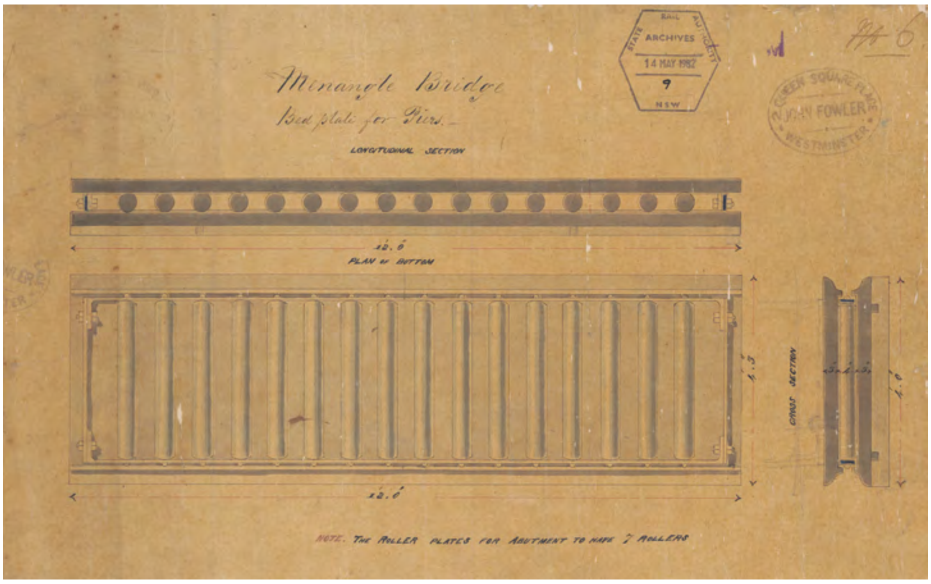
That this bridge is 150 years old — still in full service — is remarkable. That it is a bridge designed when structural engineering theory was in its infancy, fabrication techniques were limited and steel was decades away from being available for large things like bridges is even more remarkable. This is a bridge of significance — perhaps world significance.

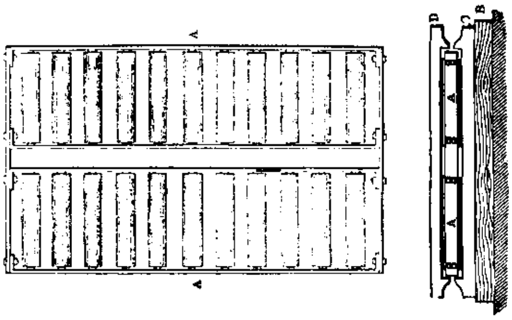
The wide use of steel and concrete reinforced by steel in modern times makes these materials so familiar that it must be remembered that there was a time when they were not widely available. Bridges were built of timber and masonry. Iron was well known but not available in the quantities needed for whole structures. Steel was known but its use was limited to tools and weapons. The first use of iron to make a whole bridge is accepted to be at Coalbrookdale in Shropshire in 1779. The best ways to use this material had to be evolved with experience, limited by the methods of producing the raw material, and the machinery available to fabricate it. Coalbrookdale is assembled from components cast in moulds and is very much derived from carpentry and joinery techniques.

The form of iron which became available in quantity is termed wrought iron. The 'wrought' adjective describes the working, the rolling and forging, which was undertaken to take the lump of iron from the furnace and turn it into a useful shape for fabrication into whatever was the task in hand. Wrought iron is essentially pure iron, but with a high proportion of impurities, usually typified as slag, in discrete grains within the whole mass. When it is worked into long or flat sections these grains become elongated and thus wrought iron has a laminar internal structure, something like plywood. In flat sections the bars and plates could be cut into short sections, stacked together, and rolled again several times. This 'refining' produced a better material but could not be done for angles and other shapes.

Steel on the other hand has none of the discrete carbon impurities, but has a small amount of carbon (or other elements in later more sophisticated steels), dissolved in the iron. If the pure iron crystal structure is imagined as an array of iron atoms arranged in perfect lines, and that these lines can unzip and zip allowing the iron to deform, the occasional out-of-gauge carbon atom snags the zipper, stops the deformation and makes the material much stronger.

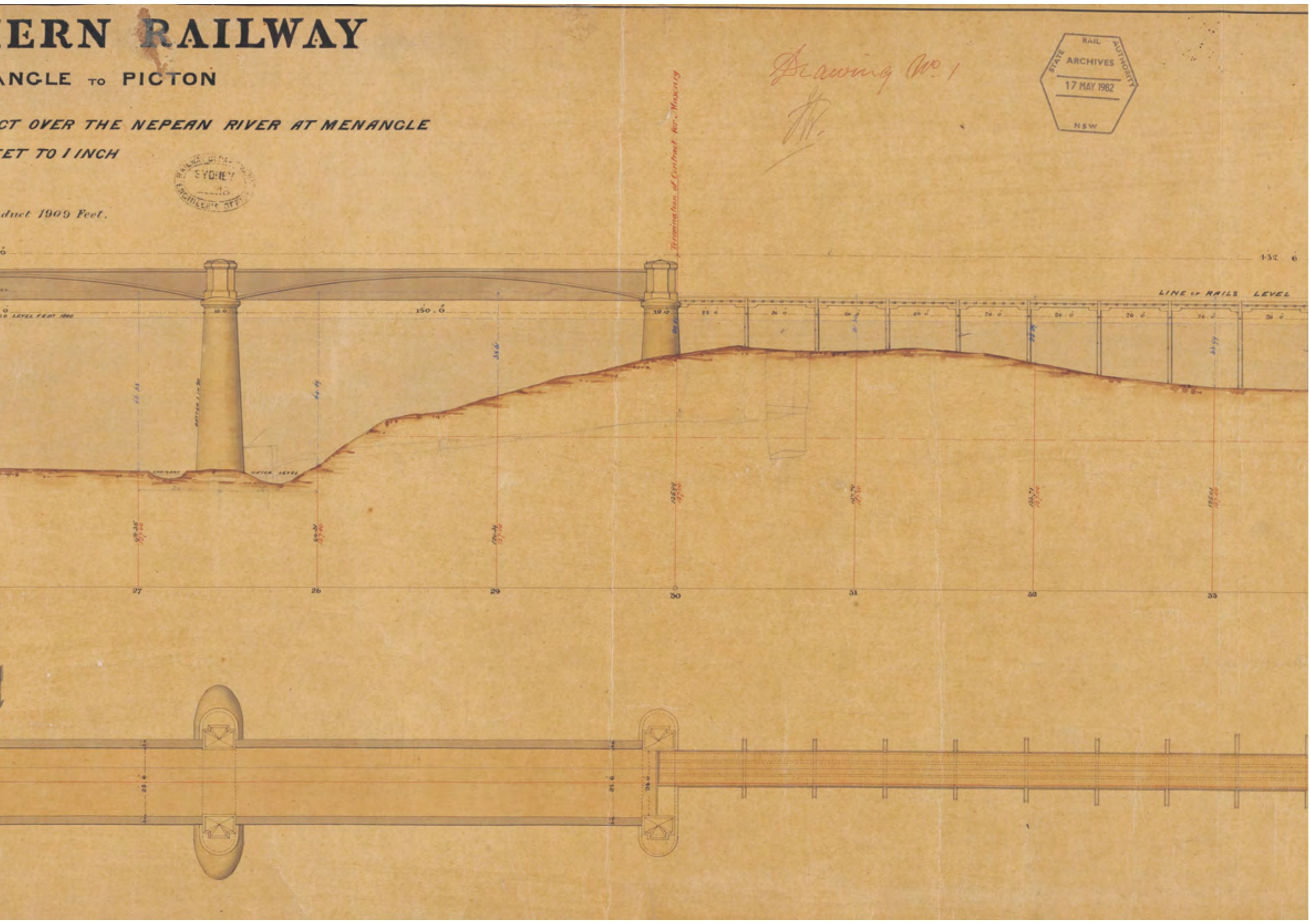


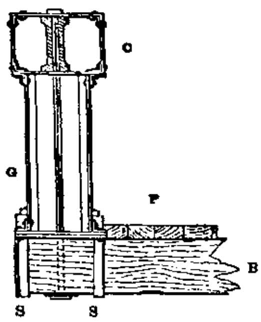




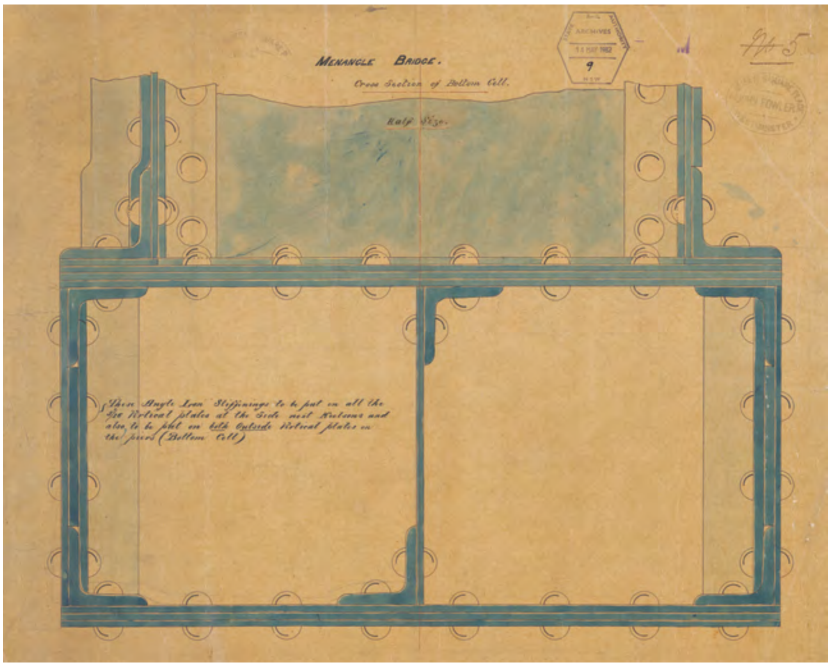
Above:
General arrangement drawing of Menangle Bridge. The plan is much longer than can be printed, but it bears the date September 1861, and is initialled "JW" above the span. Note the lightly shaded level of the 1860 flood.

Left:
The roller bearing arrangements at Menangle (upper) and Britannia (lower). The similarity is striking. Even the massive weight of Britannia is carried through timber. How the load was shared equally between all the rollers is unclear.

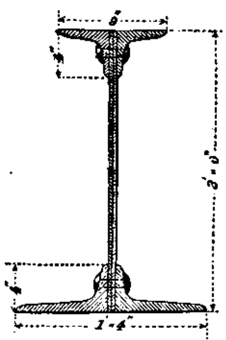




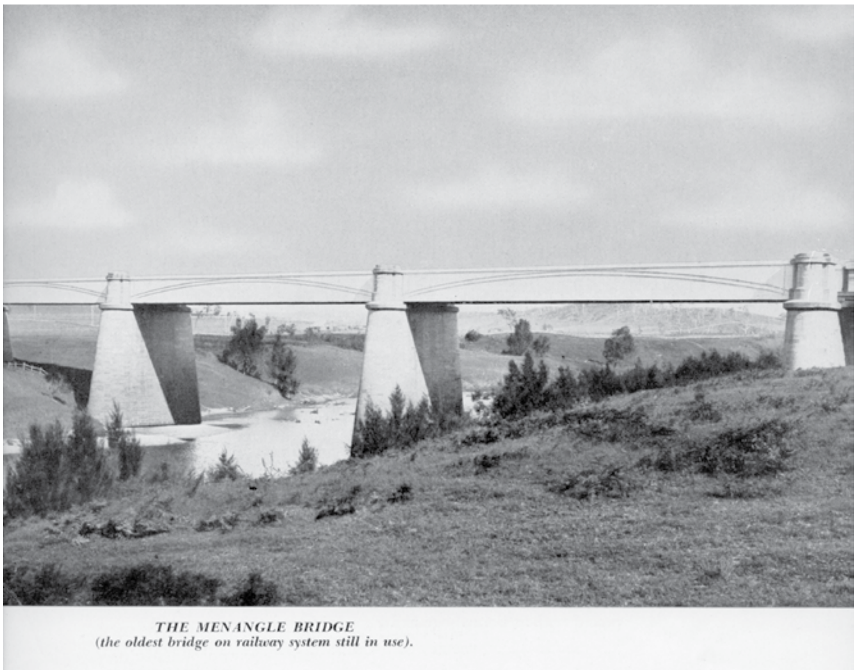
Designs were many and varied. Here the top flange is tubular, but the bottom flange isn't. The timber cross girder hangs from a large bolt through the top tube, which is saved from crushing by a cast iron spacer, as well as straps riveted to the flange.



Original plan of the details of construction of the lower tubes. At this time the only iron components available were flat plates and bars, rods, angles and 'T's. The ubiquitous modern 'I' beam was not yet available.



The alternative to a tubular girder was to use angles riveted to the vertical plate. This design was not without its usefulness, but could not tolerate large compression forces without the risk of buckling.

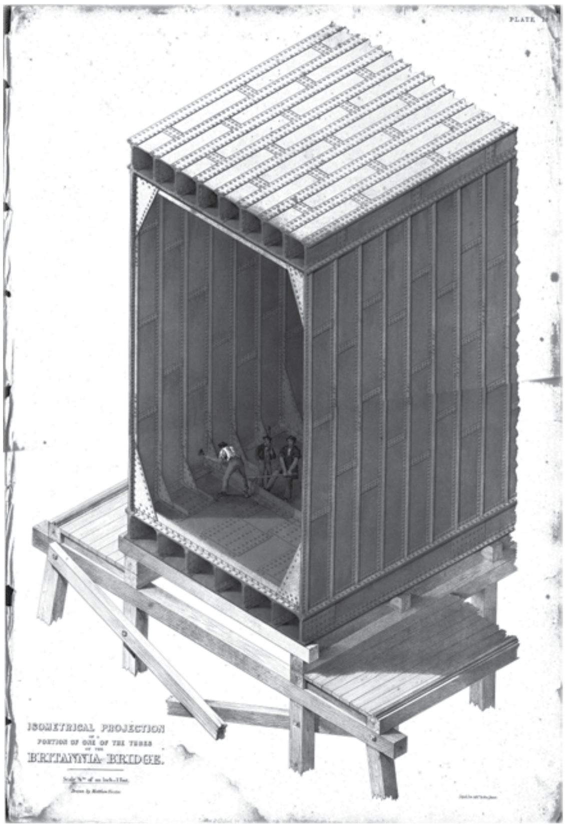


Menangle, as illustrated in the NSW Railways 1955 Centenary publication. Even then the longevity of service was worthy of note, though the picture used was itself at least 50 years old.

The economic production of steel in useable quantities is generally ascribed to Henry Bessemer in 1865, and thus years after Menangle was in service.

The superb properties of carbon mild steel soon saw it become the dominant material for iron bridges. The Hawkesbury River Bridge, designed and fabricated little more than two decades later than Menangle was wholly steel for the spans, even if the caissons were still wrought iron.

Mild steel is not only stronger than wrought iron but it is extremely malleable. While most materials stretch under load until they reach a point at which they break suddenly, mild steel keeps stretching without losing strength. This means that an overload at one point can be shed to other adjacent members without serious collapse, and that steel structures can give good warning of approaching failure and offer time to make emergency repairs, or escape to safety.



Cross section of Britannia Bridge. The similarity to Menangle of the tubular structure of the top and bottom members is evident, though the much longer span requires a higher, wider arrangement.

The most economical ways of using iron in bridges have evolved over the past two centuries and in modern times the steel truss, the welded box girder, high tensile steel cables and steel-reinforced concrete are, in a gross simplification, the accepted forms. Although the typical concrete structure displays no steel, it is very much a composite structure, for embedded within the concrete are large amounts of steel bars or tendons.

The early British civil engineers experimented with new ideas for using iron. Brunel's Saltash Bridge used a large stiff fabricated tube as an arched compression member to support the ends of a wrought iron chain, which in turn carried the deck. Equally the chain could be seen as the means of keeping the ends of the arch from spreading, and thus the arched tube carried the deck.

Thomas Telford built a suspension road bridge across the Menai Straits in Wales using wrought iron chains. Much of this work was based on experience and testing of models, as the mathematical analysis of structures, the dogma of modern engineers, was as yet undeveloped.

In a simple beam bridge under load the bottom flange is stretched and the top flange is compressed. If the tension exceeds the capacity of the material it breaks and the bridge collapses. However, while the compression of the top flange can exceed the capacity of the material and thus cause collapse, it is also possible for the compression flange to buckle and bring about the collapse of the structure. A strong cable can support many tonnes in tension as a skyhook, but nothing as a column.

For beam bridges like Menangle, engineers such as William Fairbairn, Eaton Hodginson and Robert Stephenson realised that if the compression side were not to fail by buckling it must not only have enough square inches of iron to carry the force, but those square inches would have to be arranged in such a way that they could not buckle – a tube or box. There were many designs of bridges in Europe at this time and some had a tubular top flange, like Menangle, but the bottom tension flange was just a pair of angles riveted to the vertical plate. The design was sound while the flange remained in tension, but such a bridge could never subsequently have an intermediate pier provided to halve its span.

The most dramatic example of a tubular girder is the Britannia Bridge built by Robert Stephenson and opened across the Menai Strait in 1850. Britannia was nearly three times the span of Menangle, but the techniques are the same. That Britannia was destroyed by fire in 1970 only makes Menangle more valuable. At Britannia, the span was so great and the girder so large, that

trains actually travelled inside it like a pipe, but this is not the defining 'tubular' relationship. It is the use of square tubes fabricated from many small wrought iron plates and angles as the compression flanges which is the similarity. Somewhere in history the term 'cellular' came to be used in parallel with 'tubular'.

At Menangle, two girders fabricated in much the same way as Britannia form the bridge on either side of the train. Other wrought iron tubular girders were built on the NSWGR but only Menangle survives in service. The two Wollondilly River crossings just north of Goulburn included a single 130ft tubular girder span as part of a viaduct. These spans were thus not much shorter than Menangle. They were strengthened in 1892 by the addition of an extra central pier, and the both viaducts were replaced with brick arches in 1915.

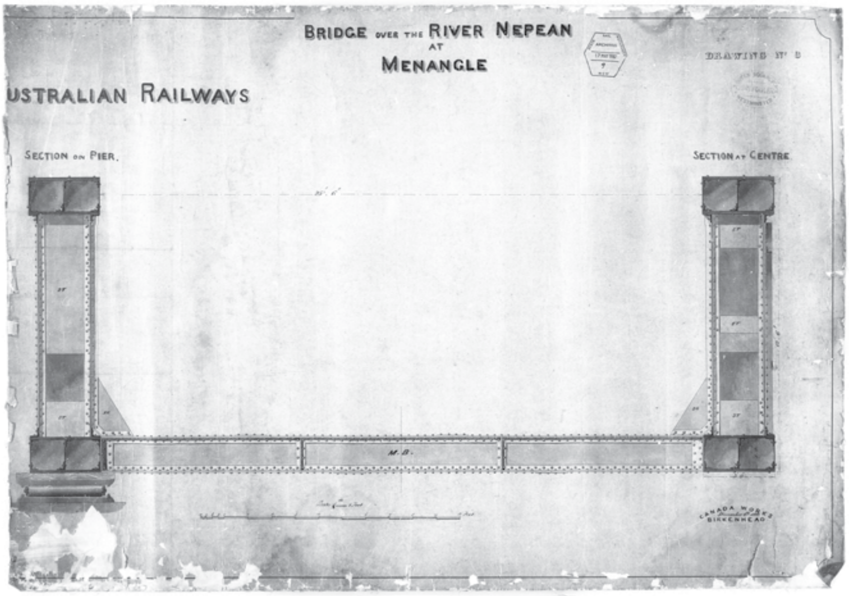
This technique in the use of iron was in parallel with the development of the lattice girder in which the lattice has the same role as the solid side plates of the tubular girder, and then into the truss, which may be thought of as a lattice with a very wide spacing. Importantly, engineering theory also advanced to a point where in a pin-jointed truss with a reasonable number of members, exact calculations of the load in every member was possible. No one could have known the details of the forces or stresses in the web plates of Menangle or the lattice array of Como and Meadowbank. In passing it should be noted that the curved line, apparent on the webs of the girders at Menangle is purely decorative. There is no arch action in the spans.

In more modern times, the availability of large plates, the development of welding, the labour cost of detail fabrication and the ongoing costs of painting a complicated truss have seen box girder bridges re-emerge as one of the preferred forms for the use of steel in bridges. The John Whitton Bridge at Meadowbank has much in common with the bridge he built at Menangle more than a century before.

Another important detail at Menangle — and one which it shares with Britannia — is that it is a continuous girder. This detail is one of the reasons why it has survived and why it was possible to strengthen it in 1907 when other bridges from the same era were abandoned. When a simple bridge span carries a locomotive it sags very slightly as it adjusts itself to the weight imposed. The ends, at the supports, tilt towards the centre, but don't help carry the load. If a series of spans are locked together at their support ends, when they try to tilt towards the centre of the span they can't and the girder works as a cantilever. Basically the bridge owner is getting double value for the material for which he has paid. The conceptual test for continuity is to ask *'could you remove a support pier without the bridge falling down?'* At Menangle you could remove several piers and the box girder would stay up, at least geometrically. (Plainly at many times the span the tubular girder might not be good enough to support its own weight.)

The near uniformity of cross section and the continuity of the girder meant that when extra piers were added, the wrought iron just kept on working as it always had done, just over six shorter spans instead of three longer ones. This solution would not have been possible on the old Hawkesbury River Bridge for example, as there, flimsy tension eye bars would have had serious compression loads applied at the changeover and would have had no chance of carrying those forces.

To be able to use continuity to advantage the support points must be accurately placed and be rigid over time. The multi span Kempsey bridge on the NSW North Coast was raised by 1.2m in the mid 1960s over a few months after floods showed it to be too low. As simple spans, this gross relocation of support points was of no consequence and trains used the bridge even as the spans were being jacked. Had it been continuous, raising one end of a span by 1.2 m would have caused mayhem throughout the remainder of the structure.



Original cross section plan. Peto, Brassey and Betts' Canada Works, Birkenhead is noted at the lower right, John Fowler's stamp of approval is top right. At lower left the girder bears on large timbers which are carried on the roller bearings.
Scan of aperture card held at NSW State Records.

The Wollondilly Viaduct near Towrang, as originally built. Later, a brick pier halved the span of the long tubular girder. The stone and brick piers are all that remain after the 1915 replacement.
ARHSnsw Railway Resource Centre 34249

A view from the north of the extensive timber approaches, which are still ballast topped. The Up track on the iron girders is obstructed by scaffolding, so this may be a pre-duplication view.
ARHSnsw Railway Resource Centre 34438

At Menangle good foundations are available and rigid piers are obtained relatively easily. If a support point settles under a continuous beam, the beam may well be no longer working the way it was intended.

The route south out of Sydney towards Goulburn, as was the first goal of the fledgling Great Southern Railway, has to cross the Nepean River. This river, which is the same river as the separately named Hawkesbury River, swings in a wide arc from its estuary north of the city, to almost reach the coast again behind the Illawarra escarpment. The Main North railway crosses it at Hawkesbury River, the Main West at Penrith, and the place chosen by Whitton for the crossing was Menangle. Earlier plans had considered a crossing at a place known as Vermont, further downstream. By the time Whitton took charge, the Great Southern Railway had reached Liverpool and the extension to Campbelltown must have been in hand, so the crossing was going to be at Menangle. The other name for the area was Riversford, so it had been a good crossing point previously.

The water catchment above Menangle is quite large and was Sydney's main water supply until the 1940s and remains a significant part of that system. The Metropolitan catchment receives abundant rainfall as moisture laden air is forced up over the escarpment. Whitton began the design of an iron bridge in 1859, but was overruled by authorities because of the expense and the need for that cash to be spent overseas. He was forced to begin designing a cheaper, locally-sourced, timber bridge. Before work could start, the massive flood of 1860 descended. William Macarthur whose estate, Camden Park, included Menangle stated that no flood like it had ever been seen in his family's long occupation of the site. The wooden bridge, had it been built, would almost certainly have been lost. Thus there was no alternative than to allow Whitton to build the iron bridge. Had the timber bridge been built, and had it survived the flood, it would have been replaced in due course and 2013 might have been its centenary and all that would survive of the 1863 bridge would be a few photos of a standard timber bridge.

The New South Wales Government appointed Captain Galton as its agent in Britain, and he in turn appointed John Fowler to supervise the fabrication of the Menangle spans. There can be little doubt that Fowler was a good choice, as he went on to build the massive Firth of Forth Bridge in Scotland, opened in 1890, and was raised to the peerage in recognition of that achievement. The problem for NSWGR Engineer-in- Chief, John Whitton, was that Mrs Whitton was John Fowler's sister. Much debate and correspondence to the letters pages of newspapers centred on the accusation that Whitton had corruptly engaged Fowler, and then over-specified the bridge to line Fowler's pockets with presumably some benefit to Whitton. In fact, Whitton had never appointed Fowler, Galton had done that, as he was empowered to do.

Whitton had worked with Fowler in England before any idea of the Engineer-in-Chief's role in NSW emerged. Whitton would have known all the other bridge engineers in England as well. It may well be that Whitton's working relationship with Fowler lead to his marriage to Elizabeth, not

The Up *Melbourne Express* crosses Menangle Bridge with 'roundtop' 3642 in in charge, c1927. Today, 3642 is a regular on Menangle Bridge.
C Haydon, ARHSnsw Railway Resource Centre 12408

that his marriage lead to the relationship with Fowler and the potential for perceived corruption.

Considering the primitive state of engineering theory the accusations seem far-fetched. DC Dalgleish, a member of the NSW parliament and Martin Gardiner, a man of some technical qualifications, were the leading critics who would in many ways make the modern 'shock jocks' seem feeble. They make much of the 'fact' that a wrought iron bridge can be made from one ton of material per foot of span, whereas Whitton's design, or Fowler's amendment of it, required two tons.

Their letters to the editor of the *Empire*, a Sydney newspaper, are long, detailed and strident, and there is a parallel tirade of abuse for *The Sydney Morning Herald*, which takes a more moderate view of the affair. The critics quote Fairbairn, a leading theorist of the day and a consultant on the Britannia Bridge, but Fowler responds to reveal that Fairbairn had revised his design methods and accepted that the older designs were too light. The Torksey Bridge near Manchester, so economically built using only one ton per foot of span is then claimed to have needed strengthening within a short period. *The Sydney Morning Herald* adopted that attitude that, even if the bridge was over-designed, the important fact was that it was sound and would be a good investment. After 150 years of service the £90,000 cost would seem to have been a wise investment. Torksey Bridge survives though much modified, unused and decrepit.

The modern reader's assessment of the debate is further confused when it is discovered that Gardiner had been dismissed by both the Victorian and NSW Railways for being quarrelsome. Accusations that Fowler owned the ironworks where the bridge was fabricated, as well as the Manning and Wardle factory from which Whitton ordered locomotives are stridently stated as facts, and then immediately absolutely denied. At this distance in time how can the truth be determined? Certainly all the players knew each other and had worked together previously. Ordering materials expeditiously from the other side of the planet without the possibility of rapid communication could never comply with later standards of propriety.

The design of the bridge should be ascribed to both Whitton and Fowler. Whitton planned the overall layout and spans and sent to Fowler a general design based on Fairbairn's theories as they were accepted when Whitton left England. Fowler did the detailed design, the precise thickness of every plate and so on using the most up-to-date theories. The same debate about the identity of the designer and the meaning of the word 'design' when applied to an iron bridge would arise again over the Sydney Harbour Bridge, between John Bradfield and Ralph Freeman, in the 1920s.

Whitton also managed to have the main spans built for double track, though even at the time there was criticism of that work and questions as to why, if he was designing for the future, Picton Tunnel was not also double track. The very similar bridge at Penrith on the western line, also across the Nepean, was similarly double track, but when the two tracks were needed a whole new bridge was provided. Perhaps it was too hard to provide the extra piers as had been done at Goulburn and Menangle. Penrith survives, but as a road bridge.

That Menangle Bridge is still in service is once again due to a fortuitous set of circumstances.

The four original piers of the crossing are made of sandstone, brought from a nearby quarry on

The bridge is close to 100 years old in this 1960s image. It has felt the weight of virtually every class of locomotive ever run in NSW, but has outlasted them all.
Bob Clarke, ARHSnsw Railway Resource Centre 354877

a light tramway, but details have not come to light. They are 80ft x 20ft at the base, tapering to 52ft x 12ft at the bearing level. The northernmost pier was easily founded on rock at a shallow depth. Rock was only found 28ft below the river bed on the third pier after much difficulty and using cofferdams and steam pumps. The southernmost pier sits on a timber platform supported by timber piles driven to a depth of between 45 and 60 feet. No details of the founding levels of the intermediate piers seem to have survived.

The extra set of cross girders, hang below the main girders on 'U' bolts. These bolts were central to the 2003 crisis and have all been replaced.
ARHSnsw Railway Resource Centre 37851

Another light railway was used in the 1920s to bring sand from a deposit upstream of the bridge, under the approach spans, and to Menangle station for loading. This was the source of the sand used in the concrete of the Sydney Harbour Bridge.

Menangle Bridge was fabricated at the Birkenhead Works of Peto, Brassey and Betts in England and sent on two ships in October 1861. The first, carrying the centre span arrived in Sydney in April 1862, but the other, carrying spans one and three, was wrecked soon after leaving Liverpool. Replacement material did not arrive in Sydney until October. It was landed at Botts Wharf in Darling Harbour, again provoking outcry as to why it had not been landed at the Government Wharf at Circular Quay. It was carried to Menangle in small tractable sub-assemblies. The many pieces were assembled on timber falsework in the river. Britannia had been cunningly pre-stressed to make it continuous even for its own self weight by erecting the shore ends of the outer spans too high and lowering them once the connection to the next span was rigid, but whether this was done at Menangle is unknown. These engineers were pushing the envelope of their science and understood what they were doing. Published figures vary, but there are about 1,000 tons of wrought iron in the spans and 245,000 rivets.

The long approaches were a series of timber openings, under what would now be the down track. On the north were 36, 26ft spans, one 25ft 6in, one 10ft and another of 4ft buried in the approach embankment. The southern approach was the same arrangement except that there were

The aftermath of the 1971 derailment. For many years the tubular construction was left exposed for appreciation, but also for entry by weather and vermin. It is now sealed, but the sandstone piers are still missing.
ARHSNSW RAILWAY RESOURCE CENTRE 17419A

only 15, 26ft spans and the short span was 13ft. As built, the approach trestles and the iron spans were ballast-topped. The northern approach trestle was much longer than the present arrangement. Duplication came in 1892, but exactly when the whole structure was changed to transom-topped is not as yet known.

With increasing train weights the capacity of the Menangle spans became inadequate. Between 1905 and 1907 three intermediate brick piers were placed to halve the effective span. This project seems to have occurred without much fanfare. Although the 1923 replacement of the approach spans in steel is covered in detail in *The Railway and Tramway Magazine* of November of that year, the extra piers are just noted as having been completed, in the NSWGR Annual Report of 1907. Other work was done at this time to provide a new set of cross girders connecting the two main members and supporting the track. The old cross girders were left in place. All of this 'modern' upgrading is now more than 100 years old, or will soon reach that timespan.

The new approach spans were not as extensive as the old timber trestle. It has been suggested by John Forsyth in his extensive line notes that the flood opening required was not as great once the Metropolitan catchment had been tamed by the water supply dams, but in 1923 only one of those dams, Cataract, was in place, and their capacity to mitigate floods, especially the very large ones, is not great. Details of the carefully planned and executed work which saw the approach spans replaced without closing the line at all are given in *ARH*, No. 884, June 2011.

In 1971 a goods train of car-carrying wagons derailed on the bridge and wagons were strewn on the ground below. Tragically for the appearance of this heritage item in its picturesque setting, some of the northern sandstone piers, above deck level, were demolished and they have never been replaced.

In 2003 a controversy erupted when fears were raised that the bridge had exceeded its fatigue life and for a time trains were stopped from using it, and then only allowed to use it a very slow speed while investigations were carried out. Eventually, the speed limit was raised to 80km/h and the assessment made that the structure is safe for at least several decades. The NSW Government was quick to promise a new bridge, on a better alignment perhaps, but once the issues were properly studied, design of the new bridge was not initiated. The bridge is now fitted with extensive scaffolding to allow frequent inspection. Menangle Bridge seems likely to remain in service for the foreseeable future. It would be good to see it recognised as the amazing structure that it is, and have its stone piers restored as it enters the second half of its second century.

The author acknowledges that he travels under the northern approach spans of Menangle Bridge twice a day on his journey to and from Macarthur Station and would dearly love to see the stone piers restored.

References

Bridges Down Under, Don Fraser, ARHS

Sydney Morning Herald, 1860–1864

The Empire, 1860–1964

Great Buildings of the World—Bridges, Derrick Beckett, Hamlyn, 1969

Original Plans held at State Records NSW

Websites of the Britannia, Torksey, Saltash, Menai Suspension Bridge

Colonial Engineer, Robert Lee, ARHS, 2000

Tubular and Other Iron Bridges, G Drysdale, Dempsey, 1850

General Description of the Britannia and Conway Tubular Bridges by a Resident Assistant 1849

Modern Examples of Road and Railway Bridges, Maw and Dredge, 1872

Britannia and Conway Tubular Bridges, Edwin Clark, 1850

Special thanks to Gordon Burr, Don Hagarty, Ken Kershaw, Tony McIlwain, Matthew Moore and Glenn Rigden. The professional, timely and enthusiastic work of the staff of NSW State Records is acknowledged.

The original coloured plans held by State Records NSW have been conserved and scanned for this article on the initiative of Matthew Moore and with the support of Engineers Australia.